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Investigations on a Slurry Drier or Calcinator.—III.

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(Concluded.)

(53) In this article an account is given of the manner in which heat is transmitted from the kiln exit gases to the material in the calcinator, and the part played by the iron bodies with which the calcinator is charged is investigated. It will be understood that many of the statements made, and the results obtained by calculation, are approximate only.

The Feeding Cycle.

(54) A cross section of the charge in the calcinator is shown in *Fig. 9*. The filling bodies (*Fig. 4*) are all drawn in end elevation to scale; actually they do not pack so regularly, but the arrangement shown is suitable for a short investigation which relates mainly to the circulation of the charge.

The movement of each filling body during the slow rotation of the calcinator can be conveniently traced by the aid of a model, which may consist of a glass jam jar lined on the inner circumference with emery cloth. The charge, approximately 47 per cent., may consist of standard sand, or preferably of $\frac{3}{16}$ -in. material. If the jar is slowly rolled along a level surface it may be seen in end view that each particle or lump turns with the jar until the upper half of the sloping surface, or chord, is reached. The material delivered falls down the chord and again commences to turn with the jar.

Referring again to *Fig. 9*, the filling body C, for instance, will pass along the circular arc C, C₁, C₂ without any movement relative to the adjacent filling bodies until on reaching the position C₂ it is thrown out on to the chord. After moving down the chord it enters, below the centre line, some other arc such as F, F₁, F₂, and the process is repeated.

(55) At regular intervals each filling body will pass through the vertical plane KL which contains the jets of slurry feed, and it is of interest to determine what the length of each interval is.

There are ten arcs of filling bodies lettered A to J and the number of bodies in each arc is marked on *Fig. 9*, the total being 161. The calcinator makes one revolution in 0.67 minute, and the 161 filling bodies shown in *Fig. 9* will be turned out on to the chord in rather less than half a revolution, or in 0.32 minute. Hence 161 filling bodies go down the chord in 0.32 minute, but since there is

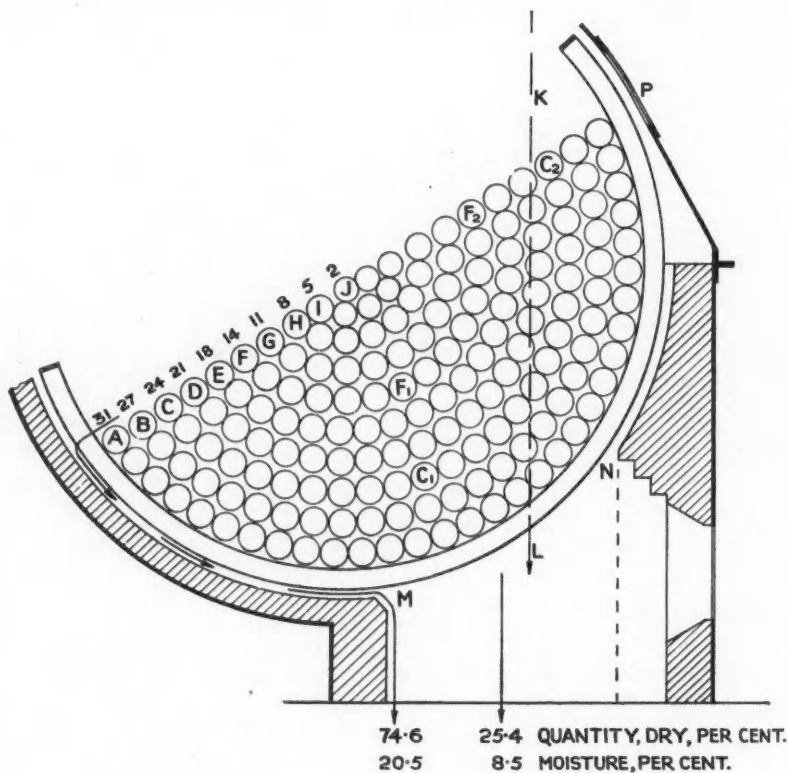


Fig. 9.

only room on the chord for twenty filling bodies in one layer the average time of passage down the chord will be

$$\frac{20}{161} \times 0.32 = 0.04 \text{ minute.}$$

Hence the filling bodies are completely circulated once every 0.36 minute.

During any circulation only the four outer rows A, B, C, and D, or 103 filling bodies, will pass through the feed plane, and the feed jets only extend for 0.80 of the calcinator width, hence the average length of a feeding cycle is

$$\frac{161 \times 0.36}{103 \times 0.80} = 0.70 \text{ minute.}$$

(56) CALCINATOR DELIVERY.—The material in the calcinator circulates with the filling bodies, but when passing down the lower half of the chord it does not easily enter between them although the interstices are relatively empty. Consequently 74.6 per cent. of the delivery, reckoned dry, passes into or through the calcinator bars at or near the toe of the slope. It is carried round and delivered into the discharge chute at point M on *Fig. 9*. The moisture in this portion averages 20.8 per cent. The remainder of the discharge takes place across the opening MN beneath the calcinator, the quantity reckoned dry being 25.4 per cent. and the average moisture 8.5 per cent.

Description of the Methods of Heat Transfer.

(57) Heat is transferred to the material in the calcinator in two stages, namely, (a) the slurry coated on the filling bodies is heated partly by the gas and partly by the iron until it is dry enough on the surface to fall away and to form individual lumps. (b) Heat is supplied from the gas to the material lumps as they move freely in the interstices of the filling bodies.

In this instance it is estimated that $54\frac{1}{2}$ per cent. of the total heat supply to the calcinator is transferred to the slurry coating, this being sufficient to raise the temperature of the layer to 212 deg. F. and to reduce the moisture content from 39 per cent. to an average of 32 per cent. Apparently it is then sufficiently dry to form into lumps which receive the balance of the heat supply. The calcinator delivers lumps which range from $\frac{1}{4}$ in. to $\frac{1}{2}$ in. in diameter.

Preliminary Data.

(58) To facilitate the calculations of heat transfer, various details of the calcinator, as obtained from the first of this series of articles (June, 1936), are set down in Table 8.

TABLE 8.
CALCINATOR DETAILS.

(a) Clinker, output per minute	261 lb.
(b) Calcinator, volume of a 47 per cent. charge	287 cu. ft.
(c) Filling bodies, number in charge	3,130
(d) Filling bodies, area of all surfaces (each)	1.0 sq. ft.
(e) Filling bodies, weight of each	7.6 lb.
(f) Mean weight of gas passing through filling bodies per minute ..	1,007 lb.
(g) Mean volume of gas passing through filling bodies per second, reckoned at 32 deg. F.	214 cu. ft.
(h) Gas temperature entering filling bodies	1,176 deg. F.
(i) Gas temperature leaving filling bodies	299 deg. F.
(j) Heat used by calcinator per minute for raising slurry temperature from 60 to 212 deg. F.	52,740 B.T.U.
(k) Total heat supply to calcinator per minute	214,270 B.T.U.

Items (c) to (e).—The filling bodies shown in *Fig. 4* were provided with windows, not indicated on the figure. A type not provided with windows and weighing 7.6 lb. is now preferred.

Items (f) to (k) are obtained from paras. (11) to (13).

Detail of Heat Supply to the Filling Bodies.

(59) It will be shown later that the slurry coating remains on the iron surfaces for 0.58 minute, and that during this period the metal temperature falls 56 deg. F. The metal is restored to its original temperature by the gas before a fresh coating of slurry is received.

The heat supply from the gases to the filling bodies and to the material coated on them is mainly by convection; hence it is necessary to find the velocity with which the gas passes between them, and also a formula based on experiment which will connect the gas velocity and the rate of heat transfer per square foot of surface per hour per deg. F. The experiments most likely to be useful in this connection are those of Reiher and others on the rate of heat transfer from hot air to rows of parallel tubes arranged as shown in *Fig. 10*, the gas flow being parallel to the plane of the paper.*

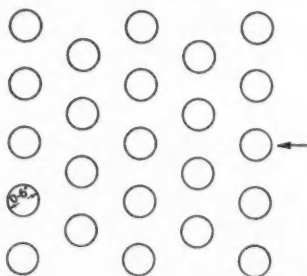


Fig. 10.

(60) FORMULA FOR H_c .—Dr. Schack gives the following formula as representative of Reiher's results when there are nine or more rows of parallel tubes.

$$H_c = \frac{V_0^{0.69}}{D^{0.31}} \quad \dots \quad (2)$$

where H_c = heat transfer in B.T.U. per square foot of surface per hour per deg. F.

V_0 = gas velocity between adjacent tubes when estimated at 32 deg. F.

D = diameter of tubes in feet.

For the present purpose the filling bodies (*Fig. 9*) are considered equivalent to nine or ten rows of parallel tubes, staggered.

(61) GAS VELOCITY (V_0).—Note items (b) and (g) of Table 8. The volume of metal in the calcinator charge is 53 cu. ft. and the volume of material is 13 cu. ft., hence the volume of the interstices to be filled with gas is 287 - 66, or 221 cu. ft. The time required for the gas (reckoned at 32 deg. F.) to pass through the interstices is therefore $\frac{221}{214}$, or 1.03, seconds.

* "Industrial Heat Transfer," by Schack, Goldschmidt and Partridge.

As measured on *Fig. 9* the mean length of the gas path through the filling bodies, with deviations omitted, is about 5 ft. ; allowing 50 per cent. extra for twists and bends, the mean path length becomes 7.5 ft. Hence the gas travels a distance of 7.5 ft. in 1.03 seconds and

$$V_0 = \frac{7.5}{1.03} = 7.3 \text{ ft. per second.}$$

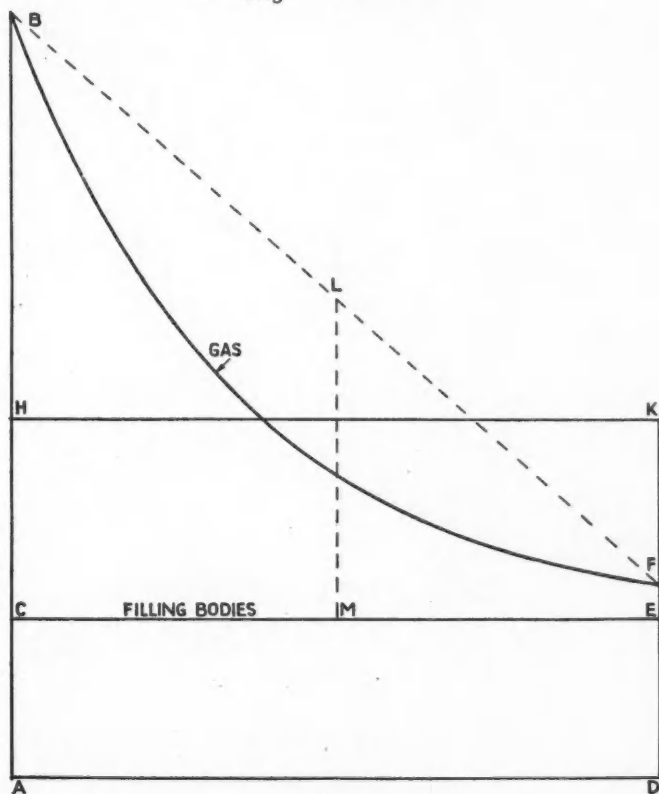


Fig. 11.

(62) Formula (2) in para. (60) is now used. Taking the mean diameter of the filling bodies at 4 in., or 0.333 ft., we have

$$H_c = \frac{(7.3)^{0.69}}{(0.333)^{0.31}} = \frac{3.94}{0.711} = 5.55$$

It is probable that the gases are more thoroughly scrubbed on passing through the filling bodies than they would be in Reiher's experiments, hence H_c is taken at 6.0.

(63) LOGARITHMIC MEAN TEMPERATURE DIFFERENCE.—The gas temperature range is given in Table 8, items (h) and (i), and the mean surface temperature of

each filling body, coated and uncoated, is assumed to be 245 deg. F. This is shown in para. (81) to be nearly correct.

To obtain the mean temperature difference for use with H_c reference is now made to Fig. 11, where the mean filling body temperature is denoted by the line CE and the gas temperature range by the line BF. The latter line falls rapidly at first since the temperature difference between the gas and the filling bodies is at a maximum. Distances measured along the line AD are proportional to the area of surface which has been traversed by the gas. It is obvious that the mean temperature difference would not be $\frac{1}{2}(BC + FE)$, or LM.

(64) When the rate of heat transmission is proportional to the temperature difference it is necessary to use the logarithmic mean. In this case it is indicated to scale by CH or EF. It is obtained as follows:

Let $\theta_1 = CB =$ temperature difference at inlet,

$\theta_2 = EF =$ temperature difference at outlet, and

$\theta_m =$ logarithmic mean temperature difference,

then

$$\theta_m = \frac{\theta_1 - \theta_2}{2.3 \log \frac{\theta_1}{\theta_2}} \quad \dots \quad (3)$$

In this instance

$$\theta_m = \frac{(1,176 - 245) - (299 - 245)}{2.3 \log \frac{931}{54}} = \frac{877}{2.85} = 308$$

(65) HEAT SUPPLY TO FILLING BODIES BY CONVECTION.—The quantity of heat transferred from the gas to the filling bodies by convection, expressed in B.T.U. per minute, is therefore

$$\frac{6.0 \times 3,130 \times 308}{60} = 96,400.$$

$H_c = 6.0$ is expressed in hours. Use is also made of Table 8, items (c) and (d).

Schedule of Heat Supply to Calcinator.

(66) It is now convenient to set down each item of the heat supply to the material in the calcinator. This is done in Table 9.

TABLE 9.

	B.T.U. per minute.
(I) Heat supplied to the filling bodies, and to the material coated on them:	
(a) By convection $H_c = 6.0$	96,400
(b) By radiation from the gas in the interstices ..	18,000
(c) By radiation from the gas in the discharge shoot to the calcinator underside	2,400
	116,800
(II) Heat supplied to the material lumps in the interstices of the filling bodies:	
(d) By convection $H_c = 12.0$, total surface 1,294 sq. ft.	94,470
(e) By radiation from the gas in the interstices ..	3,000
	97,470
Total B.T.U. per minute	214,270

This is the quantity given in Table 8, item (k).

(67) GAS RADIATION TO FILLING BODIES.—In this instance the quantity of heat transmitted by gas radiation is relatively small since the thickness of any gas layer is small. The average gas composition in the interstices can be obtained from Table 1, and the average thickness of the layer is taken at $\frac{1}{4}$ ft. The PD values obtained are $H_2O = 0.037$, and $CO_2 = 0.023$, where P is the fraction of each gas present by volume and D is the thickness of the gas layer in feet. The PD values are too small for use with the tables already published in this journal, but from data published by Dr. Schack* the gas radiation is estimated to be 8.41 B.T.U. per square foot per minute at a mean gas temperature of 900 deg. F.

The surface area of the filling bodies is 3,130 sq. ft. Using an emission and absorption factor of 0.80, the total gas radiation becomes

$$8.41 \times 3,130 \times 0.80 = 21,000 \text{ B.T.U. per minute.}$$

The material lumps in the interstices will intercept some of the gas radiation, hence the total is divided as shown in Table 9, items (b) and (e).

(68) The percentage of the total heat supply which is transmitted through the filling bodies is

$$\frac{116,800 \times 100}{214,270} \text{ or } 54\frac{1}{2} \text{ per cent. as stated in para. (57).}$$

Heat Supply to the Material Lumps

(69) It will be seen from Table 9, item (d) that in order to complete the heat supply to the calcinator it is necessary to transmit 94,470 B.T.U. per minute to the material lumps by convection. For calculation purposes the lumps are assumed to leave the calcinator as spheres $\frac{1}{2}$ in. in diameter.

METHOD OF OBTAINING H_c .—The weight of gas flowing through the filling bodies per hour per square foot of free cross section (W) is first obtained.

From para. (61) the available volume of the interstices is 221 cu. ft., and since the length of the path through the gas is taken at 7.5 ft. the mean free area in cross section for gas flow is

$$\frac{221}{7.5} = 29.5 \text{ sq. ft.}$$

Hence from Table 8, item (f),

$$W = \frac{1,007 \times 60}{29.5} = 2,050$$

Experiments made by the writer on the rate of cooling of isolated lumps of rotary clinker when fully exposed to a current of air are available. For a clinker lump $\frac{1}{2}$ in. in diameter, exposed to an air current represented by $W = 2,050$, a suitable value of H_c would be 12.0.

(70) AREA OF LUMP SURFACE REQUIRED.—The surface temperature of the partly-dried material lumps in the calcinator is taken at 212 deg. F., and the gas temperature range is given in Table 8, items (h) and (i). Hence by formula

$$(3) \theta_m = 365.$$

* "Industrial Heat Transfer," by Schack, Goldschmidt and Partridge.

Putting S for the total material surface in square feet, and remembering that H_c is expressed in hours, we have

$$\frac{12 \times S \times 365}{60} = 94,470$$

Hence $S = 1,294$ sq. ft.

(71) The moisture is reduced from 32 per cent. to 18 per cent. when the material is in lump form, and the lumps are assumed to be reduced in diameter from 0.56 in. to 0.50 in. during the drying process. With the assistance of Table 10 it is estimated that rather more than 100,000 lumps half an inch in diameter leave the calcinator per minute, the average surface area of the lumps during drying being 619 sq. ft. Hence the charge of material in the calcinator in lump form is equivalent to

$$\frac{1,294}{619}, \text{ or } 2.1 \text{ minutes' supply for the kiln.}$$

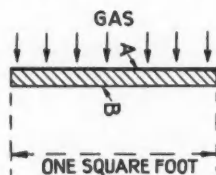


Fig. 12.

TABLE 10.
RELATING TO ONE SOLID CUBIC FOOT OF RAW MATERIAL, OR SLURRY.

	Moisture per cent.		
	18	32	39
(a) Raw material, reckoned dry lb.	104.0	73.3	61.2
(b) Water	22.8	34.5	39.1
(c) Equivalent clinker	68.6	48.4	40.4

Heat Supply to the Slurry Coating on the Filling Bodies.

(72) By assuming an average temperature for the filling bodies the heat supply to them per minute has already been obtained and recorded in Table 9. The heat exchanges between the gas, the slurry coating, and the iron surfaces of the filling bodies are now further considered, and the average temperature assumed is shown to be correct.

The slurry used at Chinnor was found by experiment in the chemical laboratory to form a coating on an iron surface 0.054 in. thick.

The volume of the slurry feed to the calcinator per minute, at 39 per cent. of moisture, will be, from Table 8, item (a), and Table 10,

$$\frac{261}{40.4}, \text{ or } 6.46 \text{ cu. ft.}$$

A coating 0.054 in. thick on all the filling body surface would amount to

$$\frac{3.130 \times 0.054}{12} = 14.08 \text{ cu. ft.}$$

This is equivalent to 2.18 minutes supply for the kiln.

(73) The calculation which follows relates to 1 square foot of the iron surface of the filling bodies, as shown at B in *Fig. 12*. The slurry coating 0.054 in. thick is shown at A.

The metal B which works in conjunction with 1 square foot of slurry coating is approximately $\frac{7}{8}$ in. thick and weighs 7.6 lb. [see Table 8, items (d) and (e)].

(74) GRAPH SHOWING TEMPERATURE VARIATIONS.—The iron plate B is assumed to receive a coating of slurry once every 2.18 minutes. During that

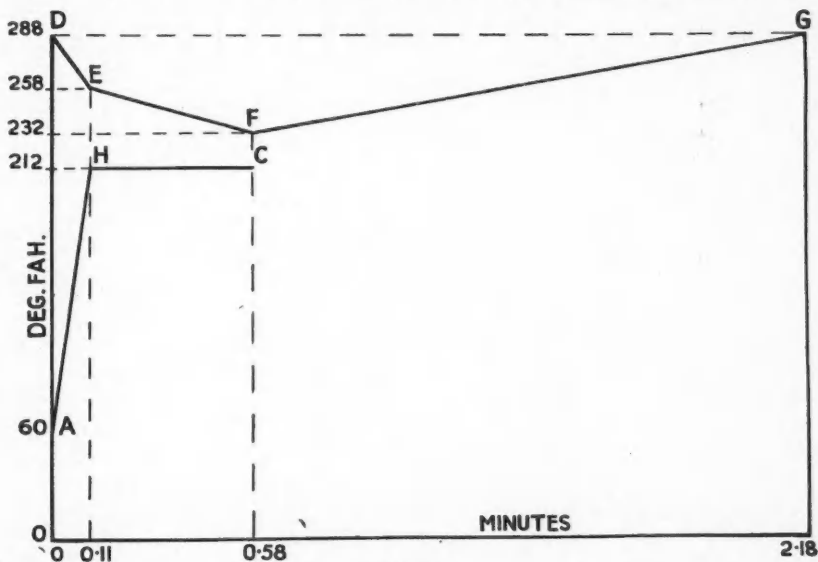


Fig. 13.

period the temperature variations of the slurry coating and of the iron plate are shown by a diagram (*Fig. 13*). The slurry coating is heated on one face by the gas and on the other face by the iron, and in two stages.

In Stage I its temperature is raised from 60 to 212 deg. F. in 0.11 minute (see line AH on the graph), and during the same period the temperature of the iron plate B falls from 288 to 258 deg. F. as indicated by the line DE.

In Stage II part of the slurry moisture is evaporated at 212 deg. F. as shown by the line HC. At point C the slurry coating leaves the iron after a heating period of 0.58 minute. The temperature of the iron plate B falls from 258 to 232 deg. F., as shown by the line EF. During the remainder of the cycle of 2.18 minutes the temperature of the iron is raised from 232 deg. F. to its original temperature of 288 deg. F. as shown by the line FG.

(75) **HEAT SUPPLY REQUIRED.**—The heat required by the slurry coating per square foot of surface during Stage I is, from Table 8, item (j),

$$\frac{52,470 \times 2.18}{3,130} = 36.7 \text{ B.T.U.}$$

The total heat required during Stages I and II is, from Table 9,

$$\frac{116,800 \times 2.18}{3,130} = 81.3 \text{ B.T.U.}$$

Hence the heat required by the slurry coating in Stage II per square foot of surface is $81.3 - 36.7 = 44.6 \text{ B.T.U.}$

Verification of Fig. 13.

(76) The particulars required for calculation purposes are as follows:

STAGE I:—	Deg. F.
(a) Gas temperature range	1,176 to 299
(b) Value of θ_m for gas and slurry coating, mean slurry temperature 136 deg. F.	474
(c) Value of θ_m for iron and slurry coating, iron 285 to 258 deg. F., slurry 60 to 212 deg. F.	114
(d) Rate of heat transfer, iron to slurry, in B.T.U. per sq. ft. per hour per deg. F., or H_{con} . [This value is used in Stage (i) of the rotary kiln calculations, see reference (j)]	150
STAGE II:—	
(a) Gas temperature range	1,176 to 299
(b) Value of θ_m gas and slurry (slurry 212 deg. F.)	365
(c) Value of θ_m iron and slurry (iron 258 to 232 deg. F. slurry 212 deg. F.)	31.2
(d) Value of H_{con}	100

As an example the value of θ_m for the iron and slurry in Stage I is worked out in detail.

$$\theta_m = \frac{(288 - 60) - (258 - 212)}{2.3 \log \frac{228}{46}} = \frac{182}{1.6} = 114.$$

(77) In Stage I the supply of heat to the slurry coating, 1 square foot in area, during 0.11 minute is

(a) By convection,	$\frac{6 \times 474 \times 0.11}{60}$	B.T.U.
(b) By gas radiation, see Table 9, items (b) and (c),	$\frac{20,400 \times 0.11}{3,130}$	5.2
(c) By conduction from the iron surface,	$\frac{150 \times 114 \times 0.11}{60}$	0.7
	$\frac{150 \times 114 \times 0.11}{60}$	30.8
Total (as required), see para. (75)		36.7

(78) In Stage II the heat supply to the slurry coating in 0.47 minute is

(a) By convection,	$\frac{6 \times 365 \times 0.47}{60}$	B.T.U.
(b) By gas radiation,	$\frac{20,400 \times 0.47}{3,130}$	17.1
	$\frac{20,400 \times 0.47}{3,130}$	3.1

(c) By conduction from the iron surface,

$$\frac{100 \times 31.2 \times 0.47}{60} \dots \dots \dots 24.4$$

Total (as required), see para. (75) $\dots \dots \dots 44.6$

(79) HEAT TRANSFER: GAS TO IRON.—During Stages I and II the heat abstracted from the iron is 30.8 and 24.4, a total of 55.2 B.T.U. This quantity of heat has to be restored to the iron in 2.18 — 0.58 or 1.60 minutes, the process being represented by the line FG on *Fig. 13*.

The particulars required for calculation purposes are:

	Deg. F.
(a) Gas temperature range $\dots \dots \dots$	1,176 to 299
(b) Mean temperature of iron surface $\frac{1}{2}(288 + 232) \dots \dots \dots$	260
(c) Value of θ_m , gas and iron $\dots \dots \dots$	278
(80) The heat supplied to the iron in 1.6 minutes is	
(a) By convection,	B.T.U.
$\frac{6 \times 278 \times 1.60}{60} \dots \dots \dots$	44.5
(b) By gas radiation,	
$\frac{20,400 \times 1.60}{3,130} \dots \dots \dots$	10.4
	<hr/> 54.9

Hence the square foot of iron plate marked "B" in *Fig. 12* takes in 54.9 B.T.U. per cycle and gives out 55.2 B.T.U. A slight adjustment is therefore required to the temperature range assumed.

The storage capacity of the iron plate is suitable. From para. (74) the weight is 7.6 lb., and its temperature range is 288 to 232, or 56 deg. F. Taking the specific heat as 0.13, the quantity of heat which it can take in or give out is

$$7.6 \times 56 \times 0.13 = 55.1 \text{ B.T.U.}$$

(81) MEAN SURFACE TEMPERATURE OF FILLING BODIES.—From *Fig. 13* the temperature of the surface exposed to the hot gases will average 136 deg. F. for 0.11 minute, 212 deg. F. for 0.47 minute, and 260 deg. F. for 1.60 minute. From these figures the mean surface temperature is found to be 243 deg. F., hence the preliminary assumption made in para. (63) was nearly correct.

Verification of Some Results Obtained by Calculation.

(82) Referring to *Fig. 9*, inspection doors marked "P" are provided in the upper portion of the calcinator casing, and when the calcinator is at work the two upper rows of filling bodies are visible as they emerge on to the chord. Their surfaces appear to be quite free from slurry. It will be seen from para. (55) that the average length of a feeding cycle is 0.7 minute, so that filling bodies approaching the feeding plane should not under average conditions have any slurry coating on them. As viewed from the inspection doors the filling bodies often pass through the feeding plane with their axes vertical, or nearly so; hence a proportion of the slurry feed should reach the interior surfaces.

The charge of material in the calcinator, including the coating on the filling bodies, is by calculation 2.68 minutes' supply, or 1,060 lb. of raw material reckoned dry. The charge has not been weighed, but from various observations made on the site this quantity appears to be approximately correct.

The Circulation of the Material Charge.

(83) The weight of material which in lump form enters and leaves the interstices of the charge per minute is now estimated. The material adhering

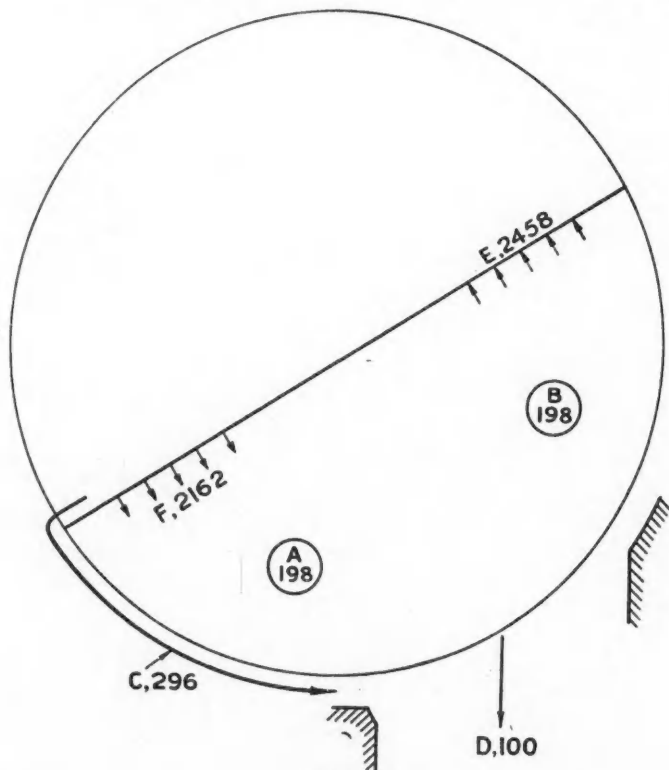


Fig. 14.

to the filling bodies is not included. A cross-section of the charge is shown in Fig. 14.

The material is thrown out on to the chord at E and re-enters the interstices at F. The figures denote the weight circulating in pounds per minute, reckoned dry. The weight leaving the calcinator per minute is shown at C and D. The figures at A and B show the weight of the coating, reckoned dry, which leaves the filling bodies per minute and passes into lump form.

The charge in lump form is 2.1 minutes' supply for the kiln, or 831 lb., but since it is circulated once every 0.36 minute, the average quantity circulated per minute is $831 \div 0.36$, or 2,310 lb. The method of obtaining the quantities at E and F is not given.

(84) The material enters into lump form when its moisture is 32 per cent. and leaves the calcinator when its moisture is 18 per cent., hence the average moisture content in the charge of lumps is approximately 25.7 per cent. Since the deliveries at C and D contain only 20.8 and 8.5 per cent. of moisture respectively, instead of 25.7 per cent. as would be expected from the rapid circulation of the charge, it is evident that the calcinator acts selectively, the relatively dry lumps being enabled to escape and the relatively wet lumps being retained.

The material leaving the filling bodies at 32.0 per cent. moisture content, as represented at A and B in *Fig. 14*, mixes with a much larger quantity of drier material in lump form, and is in turn converted into lumps. In this connection the action of the hot gases in quickly absorbing the moisture from any exposed surface is probably helpful.

How Much of the Slurry Drying Should the Calcinator Do?

(85) As mentioned in para. (6), the quantity of moisture in the material leaving the calcinator averages 18 per cent. The advantage of further drying in the calcinator is relatively small. If, for instance, the moisture is reduced to 13.8 per cent. before the material enters the kiln, the latter, as shown by *Fig. 6*, could be shortened to the beginning of Stage (5), that is to say, a length of 15.1 ft. only would be saved. Against this it is probable that the quantity of dust leaving the kiln chimney would be increased.

The calcinator is well adapted to reduce the exit-gas temperature to 300 deg. F. or less, but before Stage (5) is reached the kiln itself, due to the rising gas temperature, becomes reasonably efficient.

The Advantages of the Calcinator.

(86) (a) The iron filling bodies are not overheated (as chains may be), since they are circulated alternately through the gas entering the calcinator and through the slurry-feed plane. Their maximum temperature may not exceed 300 deg. F.

(b) The filling bodies do not have to transmit heat to the slurry after its moisture has fallen below 32 per cent., and the rate of heat transfer from iron to semi-liquid is rapid.

(c) Subsequently the material is formed into lumps and the entire surface of each lump is continuously exposed to the action of the hot gases.

(d) The lump sizes are well suited for heat reception after they have been fed to the kiln.

Grading the Kiln Chimney Dust by Sedimentation.

(87) The makers of the cyclones, Messrs. James Howden & Co. (Land), Ltd., have now graded out by sedimentation a representative sample of the dust

which passes out of the kiln chimney. A convenient horizontal cross-section of the chimney was divided into a number of imaginary squares and a stream of the mixed gas and dust was withdrawn from the centre of each square through a nozzle facing the direction of flow. Care was taken to ensure that the velocity of the gas entering the nozzle was the same as the gas velocity in the chimney nearby. The gas drawn from the chimney was filtered through an alundum porous pot. Dust samples from each collecting point were weighed and mixed to give a representative sample for the entire chimney.

(88) It was estimated in Appendix I, para. (23), that the cyclones should intercept all dust particles larger in diameter than 14 units (or 0.0014 in.), hence they should extract the same percentage of the dust entering them as a sieve having 360 meshes per lineal inch if the diameter of the sieve wire is assumed to be equal to the width of the aperture.

The sedimentation tests on the representative sample showed that only 15 per cent. of the dust particles passing up the kiln chimney were greater than 12 units in diameter, and this result is seen to be generally in agreement with the theory outlined in Appendix I.

(89) The actual weight of dust leaving the kiln chimney per hour has not been passed for publication, but it is probably not more than would be usual in a wet process kiln plant not provided with a calcinator.

Conclusion.

(90) The M.I.A.G. are to be congratulated on their technical ability and initiative, since the calcinator is the most important addition which has been made to the rotary kiln during the last thirty years. Its value was recognised at an early date by the Chinnor Cement Company, who installed the first calcinator in this country. The writer is much indebted to Mr. N. M. Benton, the managing director, for his kind permission to investigate the working of the calcinator, and to Mr. A. A. Short, director and works manager, for the supply of much interesting technical data.

[The first two articles of this series were published in this journal for June and July, 1936.]

Rock Drills and Drill Steel.—Messrs. Edgar Allen and Co., Ltd., of Imperial Steel Works, Sheffield, have issued a new "Stag" rock drill and drill steels folder. For nearly fifty years the firm has supplied large quantities of mining drill steels to the principal mining centres of the world, and particularly to the Rand mines, and also regular supplies of finished rock drills. In this folder, a copy of which will be sent to any interested reader, are outlined the various types of bits supplied by the firm with their advantages and uses. The essential features of a good rock drill are discussed, and proper rock drill treatment to obtain the best results is described. As the steel used plays so important a part in rock drill performance, the folder also contains some practical notes, with illustrations, on drill steels.

Cement Testing and "Special" Cements.

By J. H. JENNINGS, A.R.C.Sc., B.Sc.

WORKS MANAGER AND DIRECTOR, GOLDEN BAY CEMENT CO., LTD.

In an article entitled "Nachteile unserer heutigen Zement Normen," in a recent number of *Zement*, Dr. Walter Dyckerhoff deals with two questions which have caused concern to the cement manufacturer. The first is whether the demand for a great number of different hydraulic and Portland cements for special purposes recently favoured by some authorities in the United States is to be a permanent feature in cement manufacture, and the second is whether the present-day standard methods of cement testing for strength are leading the cement manufacturers in the right direction to improve the quality of their product.

"Special" Cements.

Dr. Dyckerhoff mentions cement factories in the United States which market no fewer than twelve different sorts of cements, including normal and rapid hardening Portland cements, masonry cements, waterproof cements, cements with low heat evolution, and so on. He also points out that many public authorities specify special requirements, for example, cements with not more than, say, 55 or 35 per cent. of tricalcium silicate, with not more than 5 per cent of tricalcium aluminate, cements in which the amounts of tetra calcium aluminoferrite and dicalcium silicate are restricted to narrow limits, and so on. In addition there are on the market a number of cements containing additions of burnt clay and other artificial trasses for which special claims are made. There are also so-called "waterproof" cements, although most people who have tested concrete for watertightness have come to the conclusion that, if the concrete is properly made, a good Portland cement will give results as good as those produced by any waterproof cement. With regard to cements of low heat evolution, these are not distinguished by higher concrete strengths, and for concretes giving the same ultimate strengths the disparity in heat evolution would not be nearly so great as that particular property of the cements alone would indicate.

Dr. Dyckerhoff refers to the competition to produce a "better mixed" cement, and points out that a works producing year in and year out cement of the same high unvarying quality depends for its uniformity on mixing the raw materials, mixing the clinker, and mixing the ground cement. It is impossible to do this and to produce a product of the same high degree of uniformity if the works has to produce a dozen products. He asks whether the increased number of different cements means progress in the building world, or the satisfaction of an unwise demand.

Normal methods of testing, states Dr. Dyckerhoff, have nothing whatever to do with the practical application of cement. With this statement nearly every cement maker will agree. Many will also agree that the normal methods of testing actually give deceptive results, being perhaps suitable when concrete was made with very small amounts of mixing water and much tamping and ramming,

but useless under modern conditions where the work is carried out under different conditions and with far greater proportions of mixing water. Consequently the normal methods of testing, with a constant striving for higher and higher tensile and compression strengths, have favoured the addition of materials that accentuate these properties and distracted attention from other at least as important properties of a good cement. What is required is a change in the methods of testing so that a reliable picture of the properties important in actual practice is obtained.

Dr. Dyckerhoff suggests that we have at hand a method of testing which satisfies this requirement, namely, Haegermann's method by which a mixture of standard sand and finely ground standard sand is used with cement to make a plastic mortar, which can also be used in the form of prisms to measure the shrinkage of cement. The most important difference from the old procedure is that the water-cement-ratio is changed from 0.32 to 0.60 by weight.

Effect of Admixtures.

In the case of these mixed cements, that is, cements made by grinding together Portland cement clinker and sand, slate, or similar material, the strength of the mixture if tested neat is hardly less and in some cases may actually be greater than that of the pure cement. This is also the case if the tests are carried out with the standard 3 : 1 mortar of the present-day specifications. This may be either because the additions really do assist the hardening, or because the method of testing masks the weakening of the material that has actually occurred. As soon, however, as the normal testing method is departed from, and conditions ruling in practice are more nearly reached, it is found that the latter is the case, and a very decided diminution of strength occurs and rapidly increases as the amount of the completely valueless diluent of the Portland cement clinker is increased; this occurs whether the diluent is merely finely ground sand or a proprietary material.

Dr. Dyckerhoff gives a series of tables and diagrams comparing the results of Haegermann's method with the standard method, which proves the truth of the previous statements. Indeed, they do not need any further proof to the experienced cement maker who has tested on his own works all sorts of additions to clinker, or who has had experience of some of the cements from the East, where it used to be an established practice to grind up 20 per cent. or so of sand or stone with the clinker, or even of English cements during the 'nineties when it was a common practice to do the same. These products invariably showed relatively excellent neat and 3 : 1 sand tests, and even gave excellent results when made up into a rich concrete well rammed into the moulds. What a different comparison of results was obtained, however, if the concretes were made up, say, in the proportions of eight to one! An interesting further result obtained by Dr. Dyckerhoff is that even the contraction is greater when these additions are used, and he includes in his tests a special Strassenbau mörtel which is recommended for making concrete roads, but which actually shows twice the shrinkage of Portland cement without addition!

Less striking but still noteworthy are the comparative figures given for different Portland cements tested by Haegermann's and the standard methods, from which it is clear that the two methods will often give different verdicts as to which is relatively the stronger cement, and as Haegermann's method is certainly the more nearly related to practical work it is concluded that the standard method is useless to determine which of two cements is best suited for a given purpose.

Methods of Testing.

Dr. Dyckerhoff goes on to suggest testing the fineness by measurement of specific surface, instead of by measuring the residue on a standard sieve. With

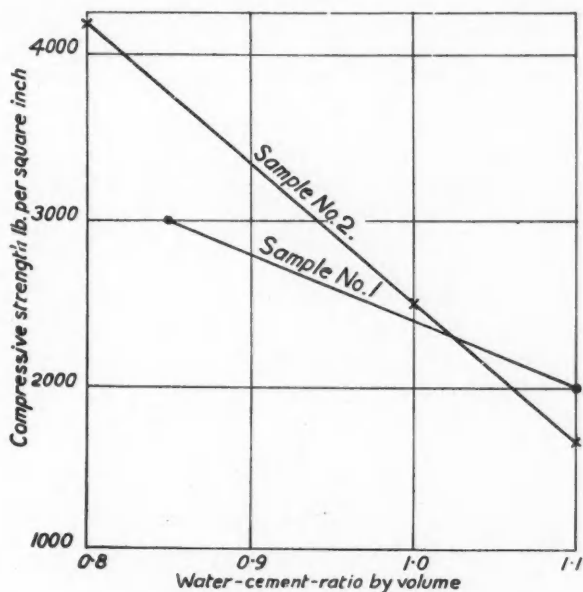


Fig. 1.

this everyone must agree, if it is considered necessary to include some such measurement in a standard specification. There seems to be, however, no particular reason why this item should be included in the specification at all, because it does not matter to the user what specific surface his cement has so long as all the other properties are satisfactory. Such measurements seem to be more necessary for works control. The writer concludes, and cement makers who have made their own investigations on this point for many years past will agree, that a Portland cement carefully prepared from suitable raw materials possesses by far the best strength as well as other qualities, gives the best results

for all purposes and in conjunction with a similarly prepared rapid-hardening Portland cement makes all substitutes and mixed products superfluous. By the use of admixtures, at the best only individual properties can be influenced, and then only at the expense of other just as important ones. A general improvement in quality is impossible on these lines, but, unfortunately, the standard specifications do not show this. The claim is constantly put forward that in this or that way a much better and cheaper cement can be made (for example, more suitable for concrete roads), a claim which is actually substantiated by the normal tests—so the sooner we change our normal tests the better.

Whilst these contentions of Dr. Dyckerhoff must meet with the wholehearted agreement of the cement manufacturer who has taken the trouble to examine his product on more practical lines than the standard method of testing affords, the question must be raised, particularly by those who have for a long time been testing their cement regularly under as nearly as possible practical working conditions, why a testing method more nearly comparable still with actual practice cannot be adopted as standard. Many manufacturers must have had to ensure that their product would really give definite concrete strengths, and the only way to find that out is by making concrete as it would be made on the job and testing it. The result of this shows that the standard tests give no criterion of what the strength of concrete with a water-cement-ratio by volume of, say, 1.0 will be. One example of this will be enough:

Days ..	Tensile strength, lb. per sq. in.				Compressive strength, lb. per sq. in.			
	1	3	7	28	1	3	7	28
Sample A ..	371	416	446	596	624	1,363	2,017	3,834
Sample B ..	311	330	402	466	823	1,736	2,509	4,146

Generally the discrepancy is greatest at early ages, as the following examples show:

Days ..	Tensile strength, lb. per sq. in.		Compressive strength, lb. per sq. in.	
	1	3	1	3
Sample C	450	511	1,562	3,095
Sample D	450	500	682	1,704

Thousands of tests show that it is impossible safely to judge the concrete strength a cement will give from the standard tests, and in this respect standard 3:1 compression tests are no better. One reason for this becomes apparent if strength/water-cement-ratio curves are drawn for different cements. A typical example is given in *Fig. 1*.

It is clear that, as the relation between strength and water-cement-ratio is not the same for different cements, the more the water-cement-ratio to be used

in practice is departed from in the method of testing the more deceptive the result will be. As it is probable that most cement is used with a water-cement-ratio of about 1.0 by volume, Haegermann's method is not far wrong so far as that is concerned. The mixture used is, however, quite different from anything used in practical work, and the question arises whether actual practical conditions cannot be more nearly imitated advantageously.

At these works for some years it has been the practice to use 3-in. concrete cubes made with a standard aggregate as the normal method of testing. It has been necessary to make standard-sand tests as well, because test sheets embodying these results have to be supplied, but the quality of the cement is judged from the manufacturing point of view entirely by the concrete tests.

For the purpose of preparing the standard aggregate, a local river gravel is sieved between the following sieves: $\frac{3}{8}$ in. to $\frac{1}{4}$ in., $\frac{1}{4}$ in. to $\frac{3}{8}$ in., $\frac{3}{8}$ in. to $\frac{1}{2}$ in., and through $\frac{1}{8}$ in. These sievings are then mixed in the proportions of 2 : 1 : 1 : 2. Six hundred grams of cement are mixed with 396 c.c. of water, and to this is added, with thorough mixing, up to 3,500 grams of the standard aggregate; sometimes, if the mixture is rather dry, not quite all the aggregate will be used. After thorough mixing the 3-in. moulds are filled to a depth of about 1 in. and rodded fifteen times with a $\frac{3}{8}$ in. rod. This is repeated until the mould is full and the mixture is then heaped up and trowelled off. The method is quick to use, and seems to be much preferable to making 3 : 1 compression tests with the hammer. The results are quite as uniform and reproducible as the standard 3 : 1 tests. Different classes of aggregate give slightly different results, but there seems to be no reason why a standard aggregate something like this should not be provided in the same way as Leighton Buzzard sand is provided now; a suitable gravel would have to be selected by the standards committee.

As the results obtained are very comparable with the actual figures obtained using a concrete mixer, it seems to be beyond question that the method is in every way preferable to the present standard method and also appears to have considerable advantage over Haegermann's method. The practical cement user appreciates the fact that it is not an artificial laboratory test, and there seems no reason why the method could not be further standardised by specifying a small mixing machine and determined times of mixing. Filling the moulds under vibration should lead to still more uniform results.

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Corrections to be Applied in Heat of Hydration Tests.

By C. DE LANGAVANT.

The following is an abstract of an article in *Revue des Matériaux de Construction* (1935, p. 91).

THE author sets out the advantages of using the vacuum flask in determining the heat of hydration of cement. As the insulation of the flask is not perfect, an allowance must be made for the heat lost by radiation and convection during the test. The object of the article is mainly to describe a method of correcting the heating curves obtained to what would be obtained under completely adiabatic conditions, i.e., when no heat is lost from the apparatus.

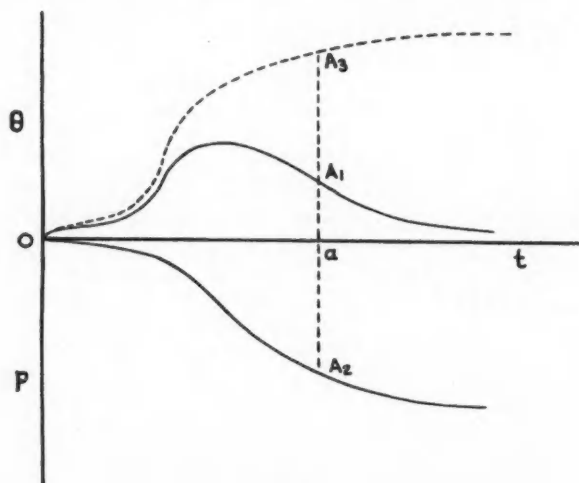


Fig. 1.

In the vacuum flask test a quantity of cement or cement and sand is gauged with the required amount of water and placed in the vacuum flask. The mouth of the flask is carefully insulated with a suitable cork through which the thermometer or thermocouple passes. The temperature is measured at the centre of the mass of cement. The curves obtained in the tests are of the shape shown at A_1 in Fig. 1. The temperature rises to a maximum and then falls when the heat loss from the apparatus is greater than the heat evolution of the cement. Curve A_2 gives the loss in temperature. The sum of curves A_1 and A_2 gives curve A_3 , which represents the curve which would be obtained under completely adiabatic conditions.

If θ = difference of temperature between the inside of the apparatus and the outside, m = the water equivalent of the vessel and its contents, α = a coefficient, and p = the loss of temperature from the commencement of the test, then

$$\frac{dp}{dt} = \frac{\alpha}{m} \cdot \theta$$

and by integration

$$p = \frac{\alpha}{m} \int_0^t \theta dt + \text{constant.}$$

When $t = 0$, $p = 0$. Hence the constant = 0.

During the time interval $t_2 - t_1 = \Delta t$ the temperature alters from θ_1 to θ_2 and the corresponding point on the curve moves from A_1 to B_1 (Fig. 2). On account of imperfect insulation during this interval there is a loss of temperature Δp . If θ_1 and θ_2 are taken close enough together

$$\Delta p = \frac{\alpha}{m} \cdot \frac{\theta_1 + \theta_2}{2} \cdot \Delta t$$

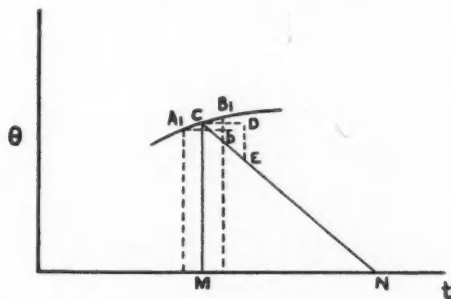


Fig. 2.

If from C, midway between A_1 and B_1 , a straight line CE is drawn such that $CD = A_1b = \Delta t$ and $DE = \Delta p$, in the similar triangles CDE and CMN

$$\frac{DE}{CE} = \frac{CM}{CN} \text{ or } \frac{\Delta p}{\Delta t} = \frac{\theta_1 + \theta_2}{2} \cdot \frac{1}{MN}$$

On comparing this with the equation $\frac{dp}{dt} = \frac{\alpha}{m} \cdot \theta$ it can be seen that MN represents

$\frac{m}{\alpha}$. MN is constant for any point C on the temperature curve. $MN = \frac{m}{\alpha}$ is

a constant characteristic of the particular apparatus. $\frac{1}{\alpha}$ is the time required for a mass equivalent to one water unit in the flask to lose a quantity of heat θ calories if the difference of temperature remains constant during this time and is equal to θ . A mass equal to m water units takes the time $\frac{m}{\alpha}$ to lose $m\theta$ calories.

If the quantity $MN = \frac{m}{\alpha}$ is known it is easy to draw the curve of loss of tempera-

ture. The curve is divided into a number of sections, not necessarily equal, in each of which the temperature may be considered practically constant. The point M having been determined by setting off $OM = \frac{m}{a}$ (Fig. 3), straight lines are drawn from M to the mean temperatures of each section on the ordinate. The drop of temperature, for instance in the interval A_1B_1 , is represented by the portion of the straight line MD included between the ordinates of A_1 and B_1 . The curve of loss of temperature is constructed by drawing lines parallel to the straight lines from M starting with O and the curve $OA_2B_2C_2D_2$ is obtained, i.e., OA_2 is drawn parallel to AM in the first section, A_2B_2 is drawn parallel to BM in

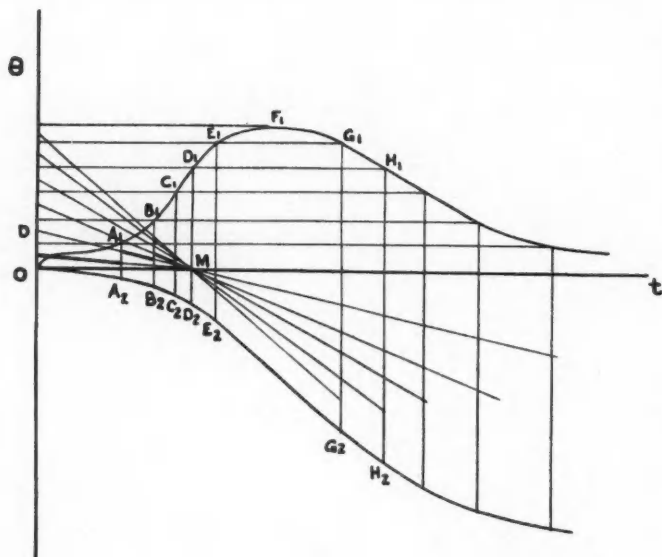


Fig. 3.

the second section, and so on. Having obtained this curve it is easy to construct the corrected curve.

The Determination of α .

The flask should be almost completely filled with water and must not be stirred or agitated during a test. The temperatures should be taken about 1 deg. C. apart. The time required for the temperature to drop 1 deg. C. is multiplied by the difference of temperature between the outside and the inside of the flask at the time of measurement. This gives $\frac{M}{\alpha}$, i.e., the time necessary for the temperature to drop θ deg. C. for a constant difference of temperature θ .

M is equal to the weight of the water in the flask plus the water equivalent of the flask and the submerged portion of the thermometer. The specific heat of the flask and thermometer can be taken as 0.2. The weight of the flask can be taken as the weight of the glass portion. Finally it is also necessary to take account of the stopper which is heated, but the weight is very small for a flask with a small neck (5 g. at most). The total weight of the inner flask with 10 cm. length of thermometer submerged, test tube, and stopper can vary from 75 to 90 g. and the water equivalent will be 16 to 18 g.

The Determination of m .

It is sufficient for the present purpose to calculate the specific heat of the mortar. The specific heat of the cement and sand is taken as 0.2 and that of combined water as 0.5, and it is assumed to be 10 per cent. by weight of the cement. For a composition comprising 25 g. cement, 750 g. sand, and 145 g. water, the specific heat is calculated as follows:

$$\begin{array}{rcl}
 1,000 \text{ g. cement plus sand at } 0.2 & = & 200 \\
 25 \text{ g. combined water at } 0.5 & = & 12.5 \\
 120 \text{ g. free water at } 1.0 & = & 120 \\
 \hline
 & & 332.5
 \end{array}$$

for a total weight of 1,145 g. The calculated specific heat is therefore $\frac{332.5}{1,145} = 0.29$, which agrees with actual determinations. For neat cement containing 290 g. of water to 1,000 g. of cement the specific heat will be 0.34. It has been found that in practice the calculated figure is a little lower than that obtained by direct measurement, hence the following figures have been adopted:

$$\begin{aligned}
 M &= \text{water} + 0.018 \\
 m &= \text{mortar} \times 0.30 + 0.018
 \end{aligned}$$

where the specific heat of the mortar has been taken as 0.30 for 1:3 mortar gauged with 14.5 per cent. water. Having determined $\frac{M}{a}$ this figure is multiplied by $\frac{m}{M}$ to give $\frac{m}{a}$ which is used for drawing the curve of loss of temperature.

(To be continued.)

Insulation of Rotary Kilns.—Two 175-ft. by 10-ft. rotary kilns at the works of the Pennsylvania-Dixie Cement Corporation have been equipped since 1929 with 6-in. by 36-in. by 2½-in. insulating blocks from a point 40-ft. from the hot end to a point 35-ft. from the slurry end. A layer of insulating cement was applied to the interior of the shell; the blocks were then laid on the cement and coated with insulating cement. The lining was covered with a 6-in. course of refractory brick. Four rows of 9-in. by 9-in. by 4-in. key fire-bricks at 90 deg. intervals were laid along the shell to keep the firebrick and insulation in position. The cost for two kilns was about £800, and one has operated 1,348 days since being lined with only minor repairs. The value of the coal saved on the two kilns is about £5,000.

Modified Standard Definition of Cement.—At the recent annual meeting of the American Society for Testing Materials, after considerable discussion concerning a proposal that it should be permissible to add substances other than gypsum and water to cement clinker for the purpose of improving the quality of rapid-hardening cement and of making easier the production of a very finely ground cement, the following revised definition of Portland cement was recommended to the Standards Committee: "Portland cement is the product obtained by pulverising clinker consisting essentially of calcium silicates, to which no additions have been made subsequent to calcination other than water and/or untreated calcium sulphate except that additions not to exceed 1 per cent. of other materials may be added, provided such materials have been shown not to be harmful by tests prescribed and carried out by Committee C-1. Note: Tests to determine whether a proposed addition is harmful will be carried out by Committee C-1, for those making requests through its Cement Reference Laboratory or other laboratory which the committee may select. As such tests are completed the committee will make known those additions which have been found not to be harmful."

Constituents of Portland Cement Clinker.—Anomalies in the properties of Portland cement indicate, states the United States National Bureau of Standards, that the compound composition of cement clinker may deviate somewhat from that ascribed to it. The structures of both commercial clinker and laboratory preparations have been investigated at the Bureau by means of the petrographic and metallographic microscopes and some preliminary observations are given in the September number of the Journal of Research issued by the Bureau. The deviation of the composition of one constituent from that of pure $3\text{CaO} \cdot \text{SiO}_2$ has been shown by microscopic structures and by X-ray patterns. The variations in optical properties of $2\text{CaO} \cdot \text{SiO}_2$ may be due to the presence of twinning bands and not to the existence of the alpha form at low temperatures. The structural characteristics of two other major constituents of clinker are also described.

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